

# Global Marine Isoprene Emission Data Derived from Satellite Ocean Color Measurements

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7<sup>th</sup> International Workshop on  
Air Quality Forecasting Research



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# Marine Isoprene Emission Data

- Currently, the NOAA NAQFC emission modeling system only considers land-based isoprene emissions, but not marine source.
  - Although the biomass over land is much larger than that in the ocean, with much larger coverage the annual net primary production of the ocean is comparable to that of the terrestrial environment.
  - **Marine Isoprene Emission** amount depends on ocean phytoplankton biomass, i.e., chlorophyll-a concentration, water clarity (i.e., water diffuse attenuation coefficient at the wavelength of 490 nm), and radiation into the water (i.e., photosynthetically available radiation (PAR)), etc.
- 
- VIIRS Ocean Color Products
  - VIIRS-derived global Marine Isoprene Emission data

The project has been supported by the JPSS Proving Ground and Risk Reduction Program.



# VIIRS Ocean Color EDR & Cal/Val Teams Members

EDR	Name	Organization	Funding Agency	Task
Lead	<b>Menghua Wang (OC EDR &amp; Cal/Val Lead)</b> , L. Jiang, X. Liu, W. Shi, S. Son, L. Tan, X. Wang, J. Sun, K. Mikelsons, V. Lance, <b>M. Ondrusek</b> , E. Stengel	NOAA/NESDIS/ STAR	JPSS/NJO	Leads – Ocean Color EDR Team & Cal/Val Team OC products, algorithms, SDR, EDR, Cal/Val, vicarious cal., refinements, data processing, algorithm improvements, software updates, data validations and analyses
Ocean Color	<b>Robert Arnone</b> Sherwin Ladner, Ryan Vandermeulen Adam Lawson, Paul Martinolich, Jen Bowers	U. Southern MS NRL QinetiQ Corp. SDSU	JPSS/NJO	Satellite data evaluation, in situ data Look Up Tables – SDR-EDR impacts, vicarious calibration Satellite matchup tool (SAVANT) – Golden Regions Cruise participation and support WAVE_CIS (AERONET-OC site) operation
	<b>Carol Johnson</b>	NIST	JPSS/NJO	Traceability, AERONET-OC Uncertainty
	<b>Curt Davis</b> , Nicholas Tufillaro	OSU	JPSS/NJO	Ocean color validation, Cruise data matchup West Coast
	<b>Burt Jones</b> , Matthew Ragan	USC	JPSS/NJO	Eureka (AERONET-OC Site)
	<b>Sam Ahmed, Alex Gilerson</b>	CUNY	JPSS/NJO	LISCO (AERONET-OC Site) Cruise data and matchup
	<b>Chuanmin Hu</b>	USF	JPSS/NJO	NOAA data continuity, cruise participation/support
	<b>Ken Voss &amp; MOBY team</b>	RSMAS –Miami	JPSS/NJO	Marine Optical Buoy (MOBY)
	<b>Zhongping Lee</b> , Jianwei Wei	UMB	JPSS/NJO	Ocean color IOP data validation and evaluation Ocean color optics matchup, cruise participation

Working with: NOAA **CoastWatch**, VIIRS **SDR team**, DPA/DPE, Raytheon, NOAA OC Working Group, NOAA Coral Reef Watch, NOAA various line-office reps, NASA OBPG, NOAA OCPOP, etc.

Collaborators: D. Antoine (BOUSSOLE), B. Holben (NASA-GSFC), G. Zibordi (JRC-Italy), R. Frouin (for PAR), and others. 3 3



# Summary of VIIRS Ocean Color EDR Products



- **Inputs:**
  - VIIRS M1-M7 and the **SWIR M8, M10, and M11** bands SDR data
  - Terrain-corrected geo-location file
  - Ancillary meteorology and ozone data
- **Operational (Standard) Products (8):**
  - Normalized water-leaving radiance ( $nL_w$ 's) at VIIRS visible bands M1-M5
  - Chlorophyll-a (Chl-a) concentration
  - Diffuse attenuation coefficient for the downwelling spectral irradiance at the wavelength of 490 nm,  $K_d(490)$  (New)
  - Diffuse attenuation coefficient of the downwelling photosynthetically available radiation (PAR),  $K_d(\text{PAR})$  (New)
  - Level-2 quality flags
- **Experimental Products:**
  - Inherent Optical Properties (IOP-a, IOP- $a_{\text{ph}}$ , IOP- $a_{\text{dg}}$ , IOP- $b_b$ , IOP- $b_{\text{bp}}$ ) at VIIRS M2 or other visible bands (M1-M5) from the Quasi-Analytical Algorithm (QAA) (Lee et al., 2002)
  - Photosynthetically Available Radiation (PAR) (R. Frouin)
  - Chlorophyll-a from ocean color index (OCI) method (Hu et al., 2012)
  - Others from users requests
- Data quality of ocean color EDR are extremely sensitive to the SDR quality. It requires ~0.1% data accuracy (degradation, band-to-band accuracy...)!



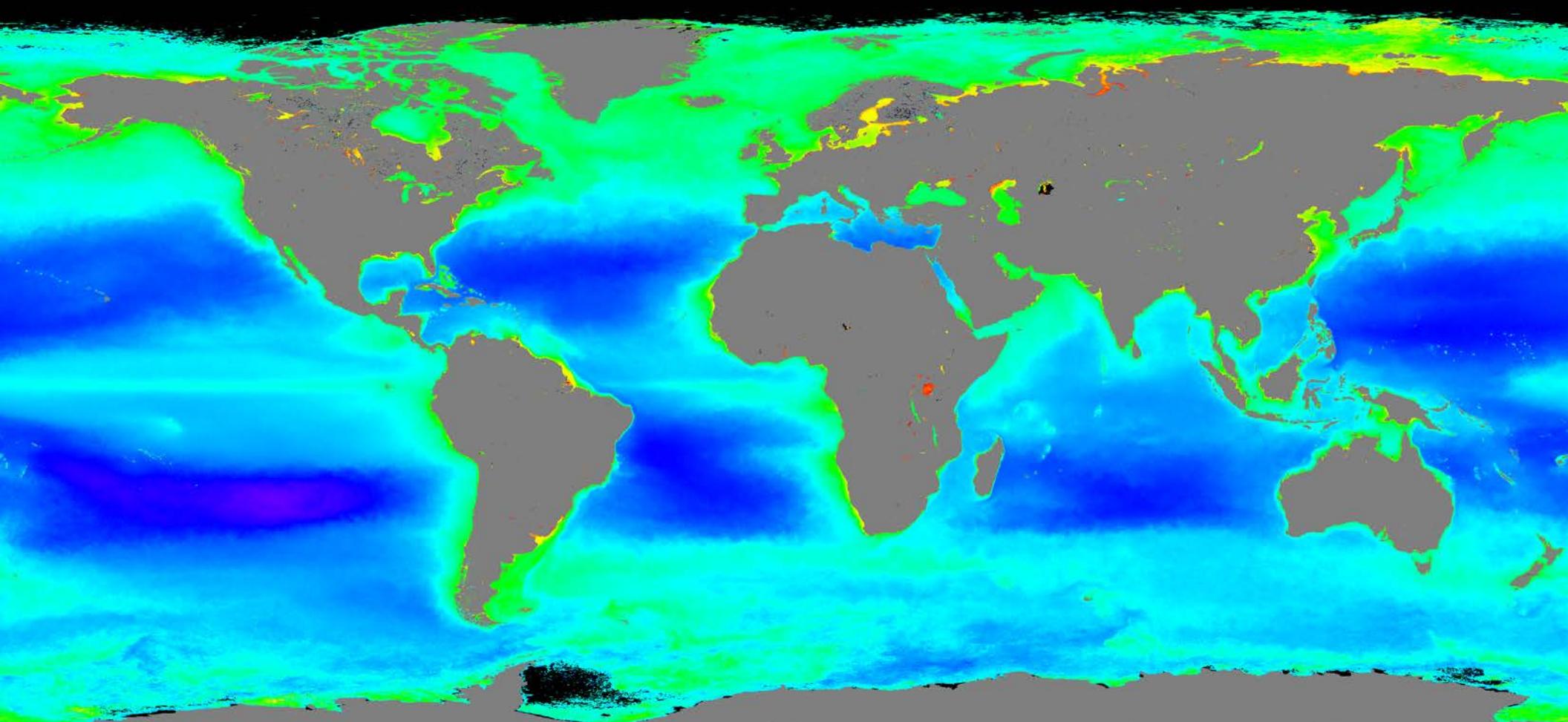
# End-to-End Ocean Color Data Processing



- NOAA Ocean Color Team has been developing/building the capability for the **End-to-End** satellite ocean color data processing including:
  - Level-0 (or Raw Data Records (RDR)) to Level-1B (or Sensor Data Records (SDR)).
  - Level-1B (SDR) to ocean color Level-2 (Environmental Data Records (EDR)).
  - Level-2 to global Level-3 (**routine daily, 8-day, monthly, and climatology data/images**).
  - Validation of satellite ocean color products (in situ data and data analysis capability).
- Support of in situ data collections for VIIRS Cal/Val activities, e.g., **MOBY**, **AERONET-OC sites**, **NOAA dedicated cruise**, etc.
- On-orbit instrument calibration (**solar and lunar**) for ocean color data processing (**Cal effort is needed to meet ocean color requirement**):
  - J. Sun and M. Wang, “Radiometric calibration of the VIIRS reflective solar bands with robust characterizations and hybrid calibration coefficients,” *Appl. Opt.* (Submitted).
  - J. Sun and M. Wang, “On-orbit calibration of Visible Infrared Imaging Radiometer Suite reflective solar bands and its challengers using a solar diffuser,” *Appl. Opt.*, **54**, 7210-7223, 2015.
  - J. Sun and M. Wang, “On-orbit characterization of the VIIRS solar diffuser and solar diffuser screen,” *Appl. Opt.*, **54**, 236-252, 2015.
  - J. Sun and M. Wang, “Visible Infrared Imaging Radiometer Suite solar diffuser calibration and its challenges using solar diffuser stability monitor,” *Appl. Opt.*, **53**, 8571-8584, 2014.
- RDR (Level-0) to SDR (Level-1B) data processing (**needed for quick data reprocessing**):
  - Sun, J., M. Wang, L. Tan, and L. Jiang, “An efficient approach for VIIRS RDR to SDR data processing,” *IEEE Geosci. Remote Sens. Lett.*, **11**, 2037–2041, 2014.
  - L. Tan, M. Wang, J. Sun, and L. Jiang, “VIIRS RDR to SDR Data Processing for Ocean Color EDR,” *Proc. SPIE 9261, Ocean Remote Sensing and Monitoring from Space*, October 13-16, 2014.



# VIIIRS Climatology Chlorophyll-a Image (April 2012 to October 2014)



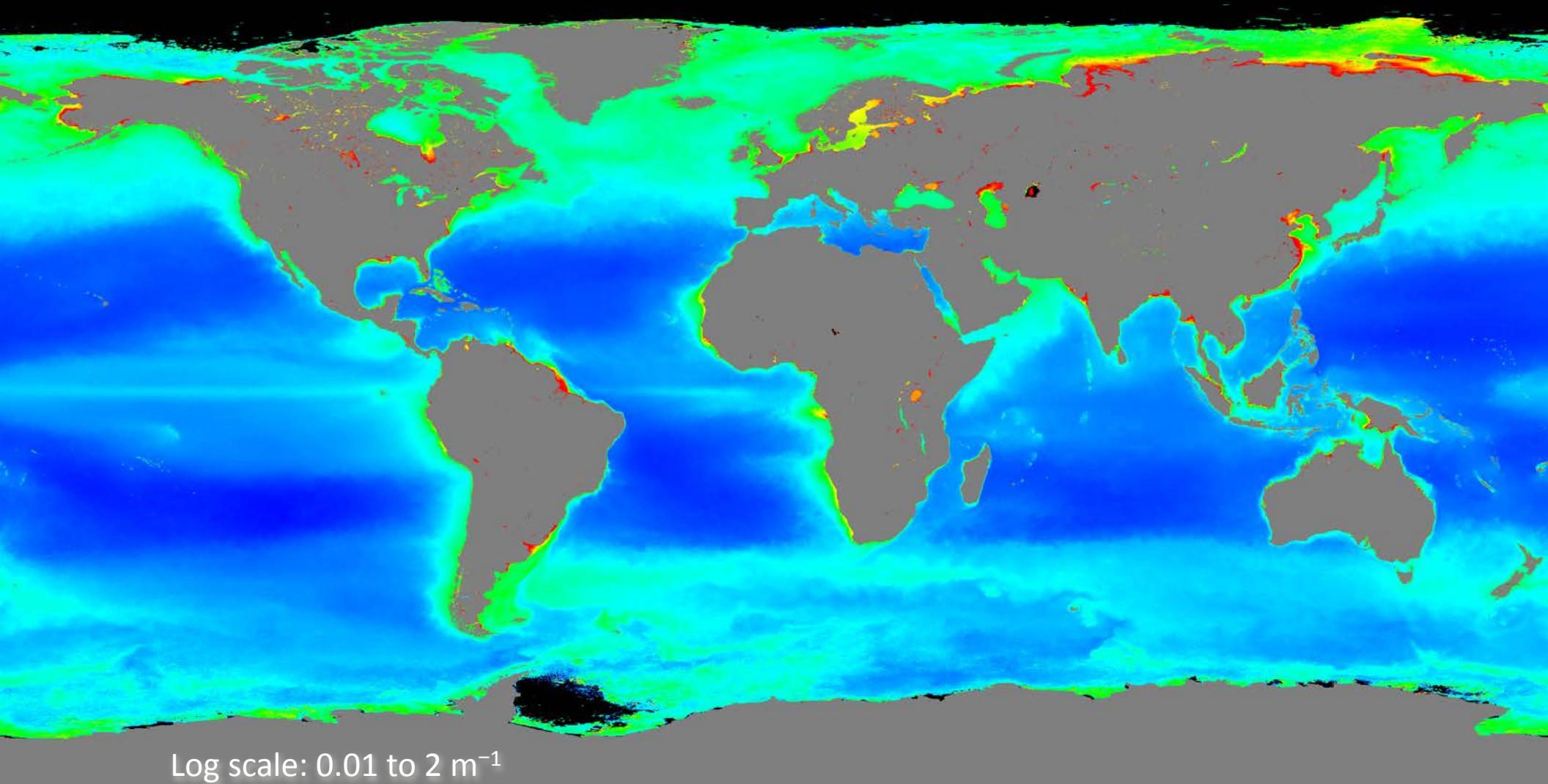
Generated using MSL12 for VIIIRS ocean color data processing

Wang, M., X. Liu, L. Tan, L. Jiang, S. Son, W. Shi, K. Rausch, and K. Voss, "Impacts of VIIIRS SDR performance on ocean color products," *J. Geophys. Res. Atmos.*, **118**, 10,347–10,360, 2013.  
<http://dx.doi.org/10.1002/jgrd.50793>



# VIIRS Climatology $K_d(490)$ Image

## (March 2012 to February 2015)

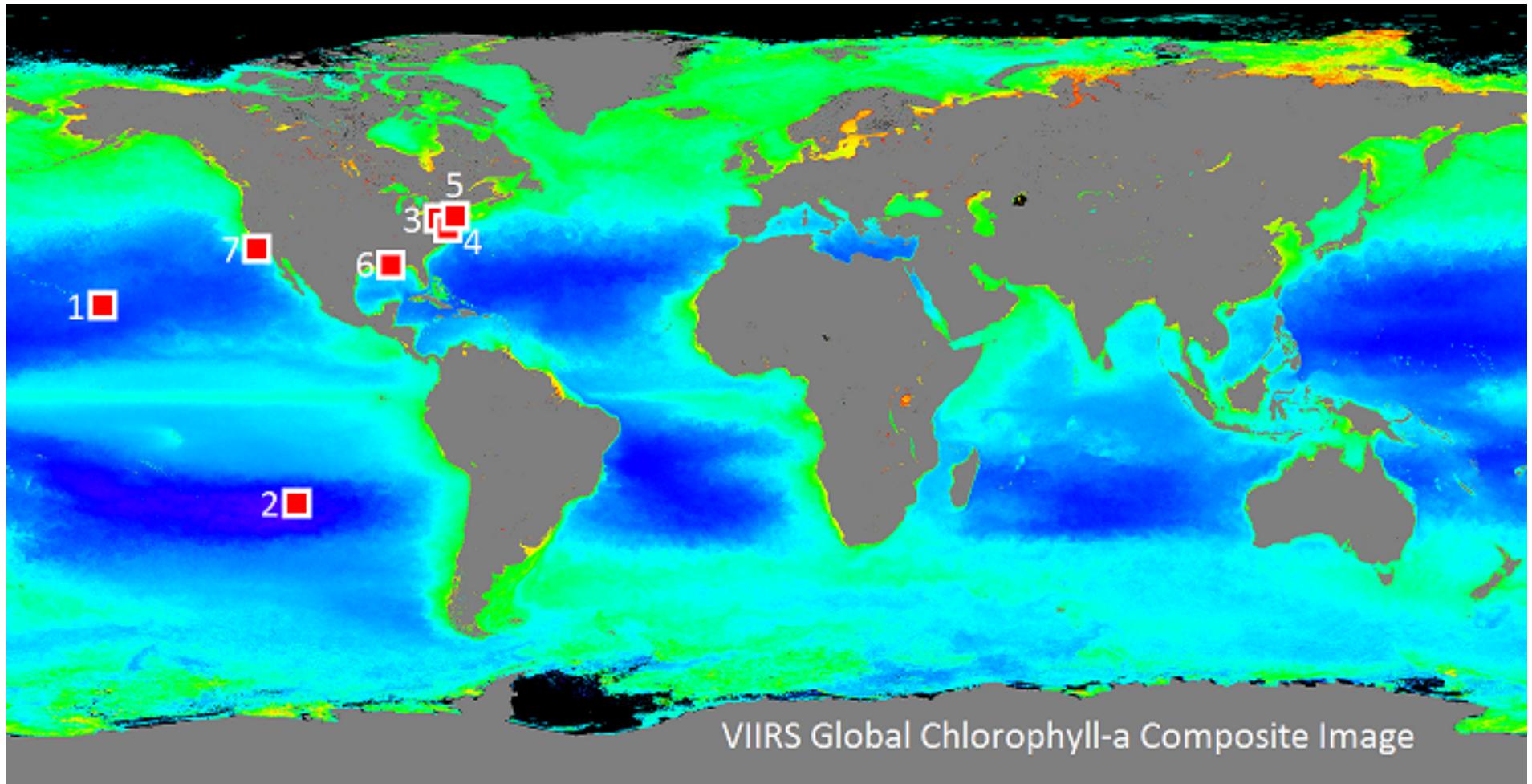


Log scale: 0.01 to 2 m<sup>-1</sup>

**Generated using MSL12 for VIIRS ocean color data processing**

Wang, M., S. Son, and L. W. Harding Jr., "Retrieval of diffuse attenuation coefficient in the Chesapeake Bay and turbid ocean regions for satellite ocean color applications," *J. Geophys. Res.*, **114**, C10011, 2009.  
<http://dx.doi.org/10.1002/2009JC005286>

# VIIIRS Ocean Color EDR Monitoring Sites

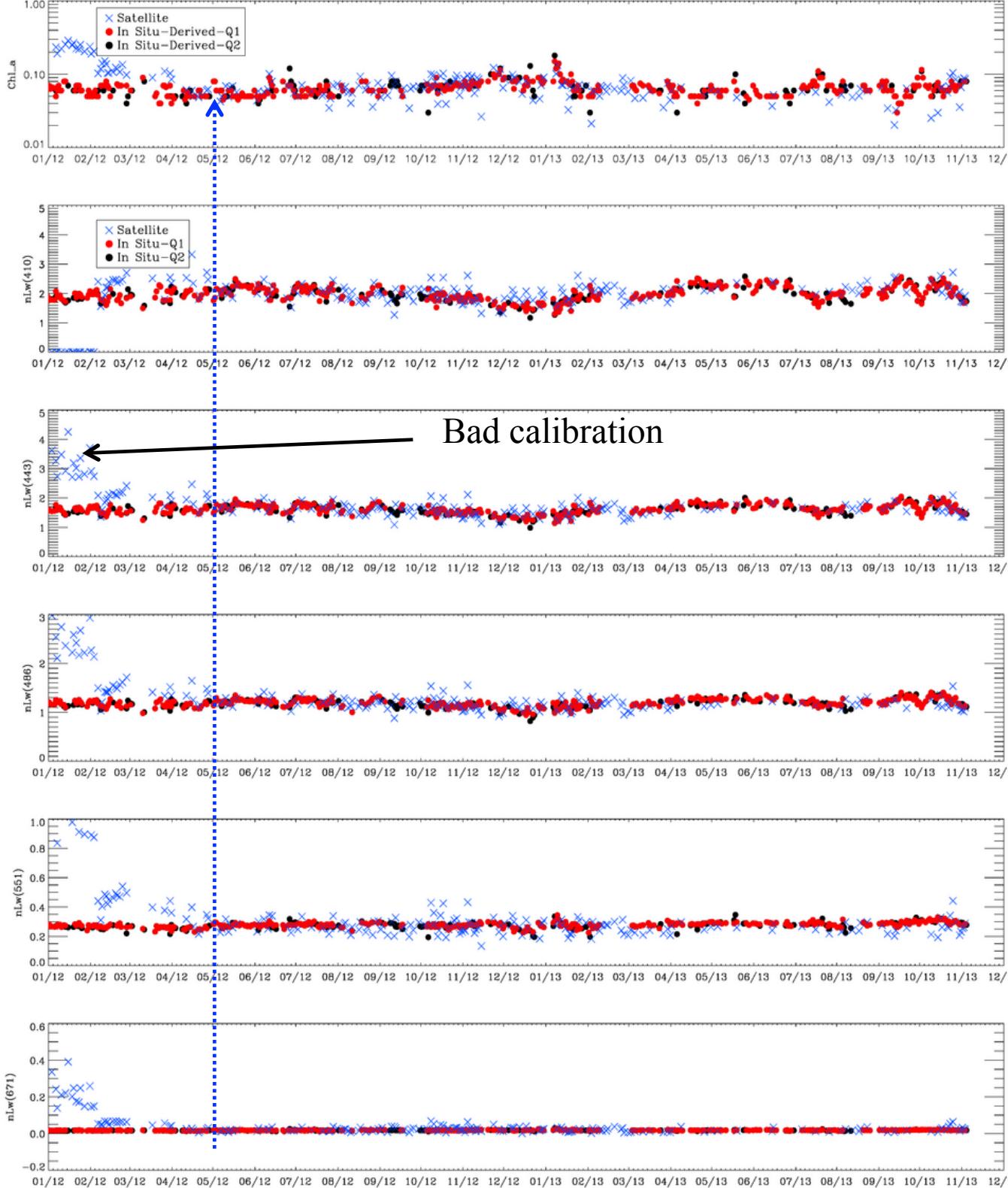


1. MOBY Site; 2. South Pacific Gyre; 3. Chesapeake Bay; 4. US East Coast; 5. AERONET-OC CSI Site; 6. AERONET-OC LISCO Site; 7. AERONET-OC USC Site.

**Website:**

<http://www.star.nesdis.noaa.gov/sod/mecb/color/>

Satellite data were extracted using 11x11-bin box average from 1-km L3 file. In Situ data: Q1 – MOBY Quality 1; Q2 – MOBY Quality 2.



# MOBY

Comparison of NOAA VIIRS ocean color products with  
**Marine Optical Buoy (MOBY)** in situ data.

Note:

Vicarious calibration gains applied since **May 2012**.

Vicarious gains were derived using **MOBY** in situ data.

**MOBY** in situ optics data have been providing critical data set in support of VIIRS calibration and validation activities, including VIIRS Level-1B (SDR) data monitoring for sensor on-orbit calibration.

**MOBY** Matchup

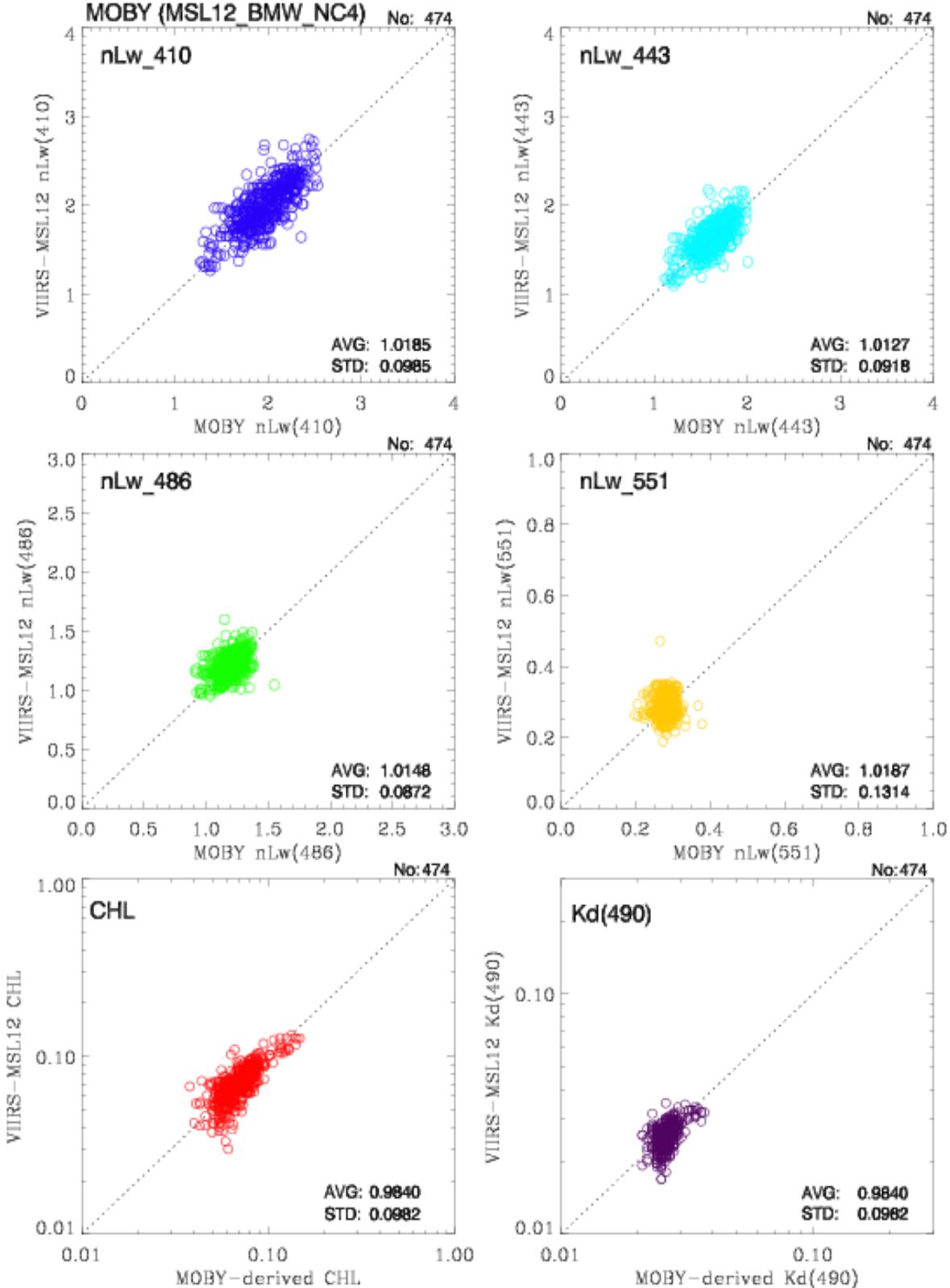
with

**VIIRS OC-SDR/EDR  
Processing  
(BMW-netCDF4)**

**MOBY**

(2012-01-01 ~  
**2015-07-22**)  
Q1+Q2, ±3hr

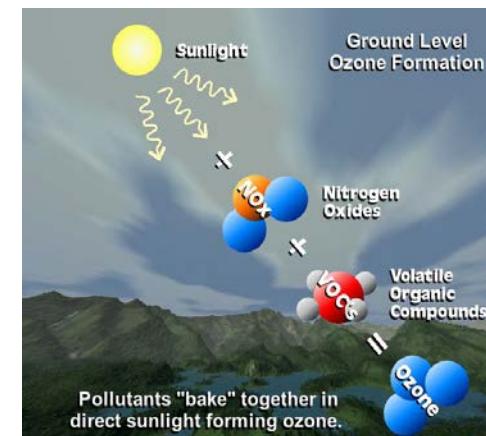
**Use OC-SDR  
with  
New MSL12**



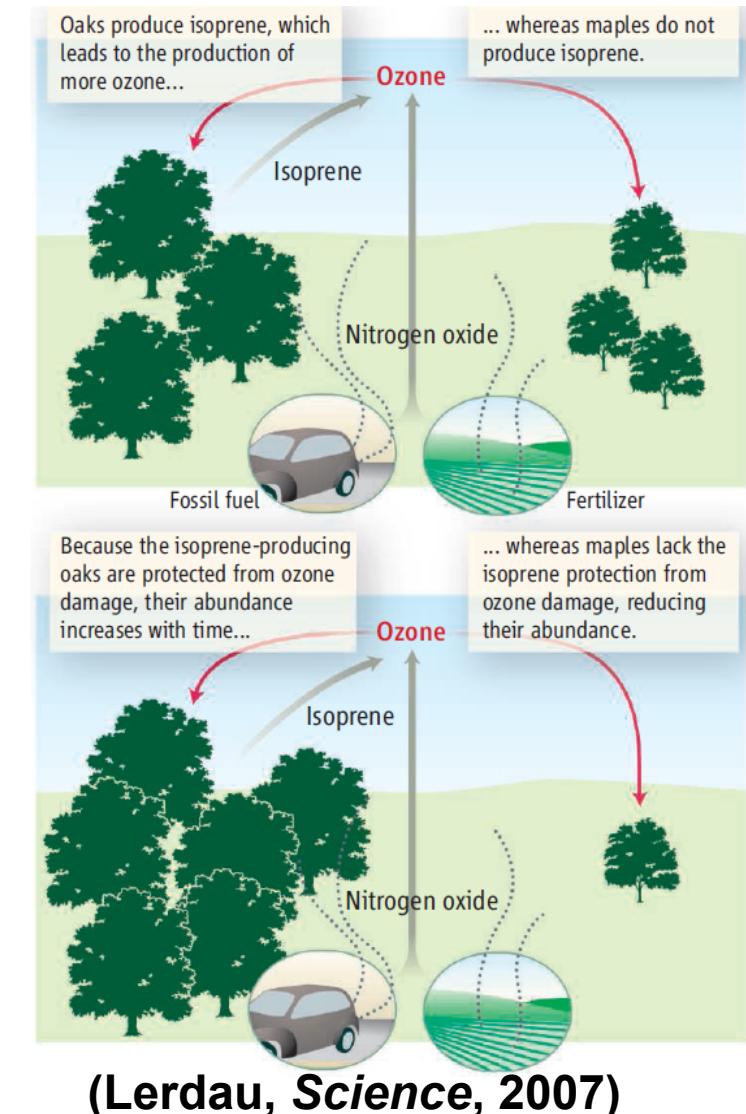
# Why is Isoprene Important?

Isoprene ( $\text{CH}_2=\text{CH}-\text{C}(\text{CH}_3)=\text{CH}_2$ ) is a biogenic hydrocarbon emitted by trees, grasses and ocean phytoplankton.

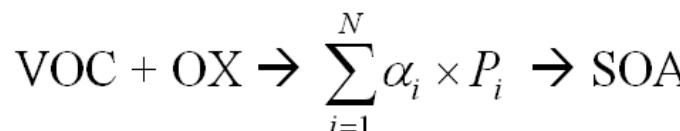
- ❖ Purpose of emission: combat abiotic stresses;



- ❖ Ozone formation:



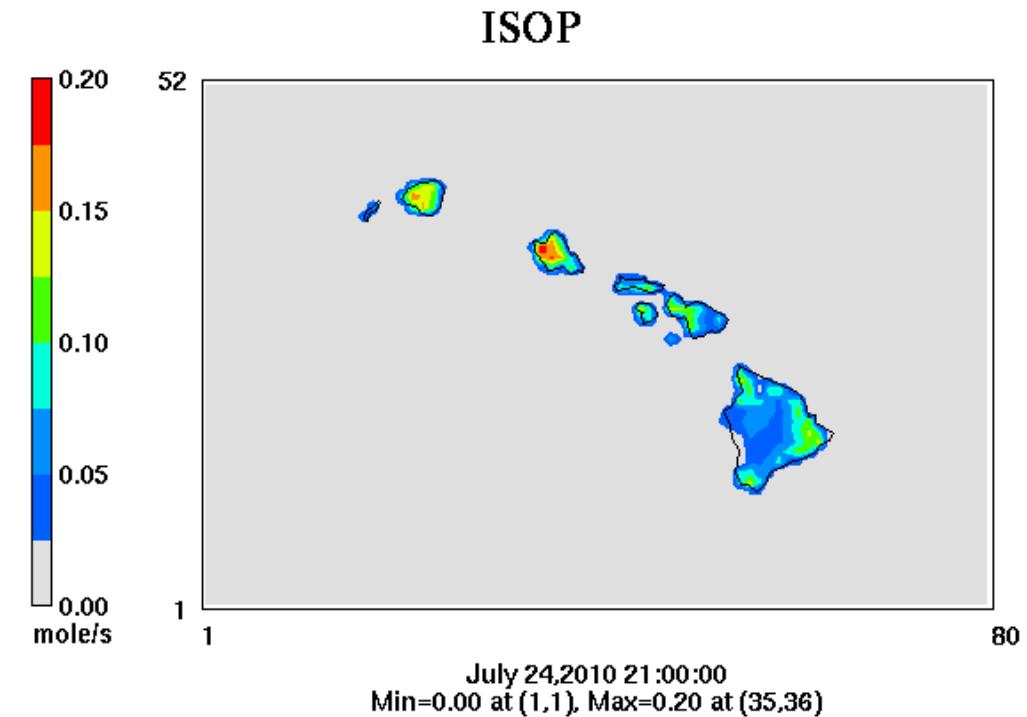
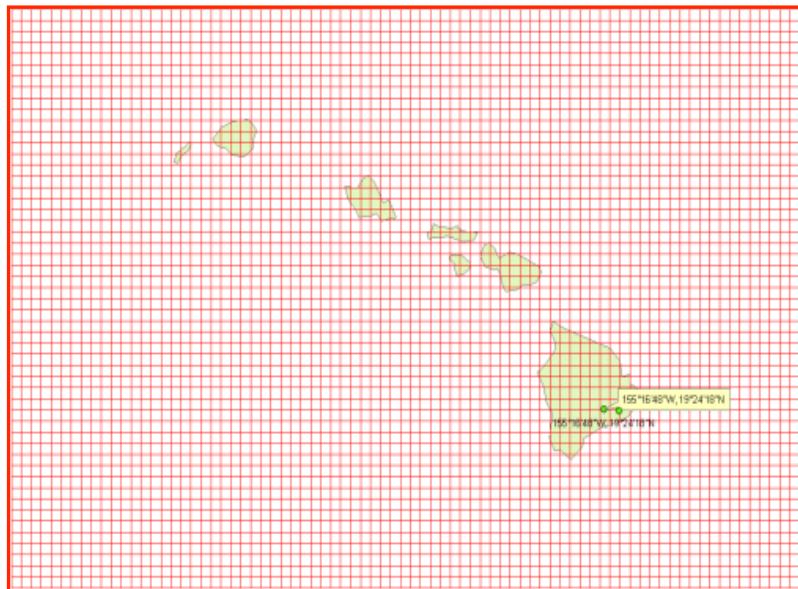
- ❖ Aerosol formation:



- ❖ Cloud formation: Cloud Condensation Nuclei (CCN);

**Ozone, Aerosol, cloudiness all at the central stage of climate change debate**

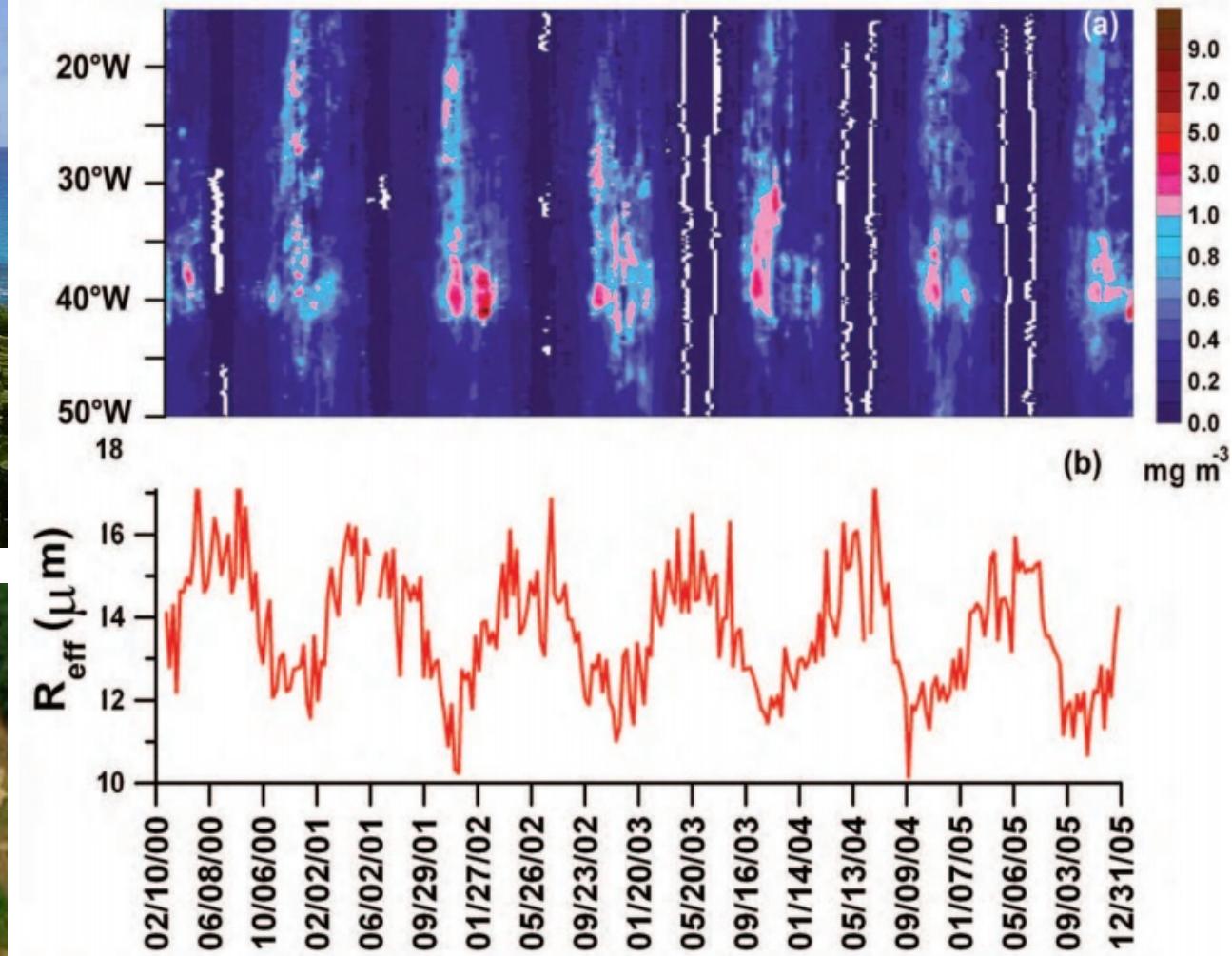
# National Air Quality Forecast over Hawaii



A suite of reactive gases and aerosols emitted from the Ocean:

- ❖ Isoprene;
- ❖ Dimethyl Sulfide (DMS);
- ❖ Organic Aerosols;

# Algae Bloom and Atmosphere Cloudiness



(Meskhidze and Nenes, 2006)

# A Review of Approaches for Marine Isoprene Emissions

## ❖ Shaw et al. (2003):

$$E_{iso} = [Chl-a] * V * EF$$

## ❖ Palmer & Shaw (2005):

$$E_{iso} = K_{AS} * (C_W - H * C_A)$$

$$P - C_W(k_i * C_{Xi} + k_{bio} + k_{AS} / Z_{ML}) - L_{MIX} = 0$$

$k_i$  – chemical reaction rate for oxidant i;

$k_{bio}$  – bacterial loss rate;

$L_{MIX}$  – loss due to downward mixing;

## ❖ Gantt et al. (2009):

$$E_{iso} = SA * H_{max} * [Chl-a] * F_{iso} * \int_0^{H_{max}} Pdh$$

$E_{iso}$  - Isoprene emission;

$[Chl-a]$  - Isoprene emission;  
 $V$  – euphotic water volume;

$EF$  – Emission factor;

$k_{AS}$  – exchange coeff.;

$C_W$  – isop. conc. in water

$C_A$  – isop. conc. in the air

$H$  – Henry's law constant;

$P$  – isoprene production;

$H_{max}$  – euphotic zone depth;

$Z_{ML}$  – mixing layer depth;



# JPSS Marine Isoprene Algorithm (V1.0)

- ❖ Built upon several pioneering works:

$$F = a \times [Chl] \times \sum_{i=1}^N (EF_i \times f_i) \times H_{\max} \times \gamma$$

JPSS Products Used:

- [Chl-a]
- $K_d(490)$
- PAR

Euphotic zone height (Gantt et al., 2009)

$$H_{\max} = \left( -\ln\left(\frac{2.5}{I_0}\right) / K_d(490) \right)$$

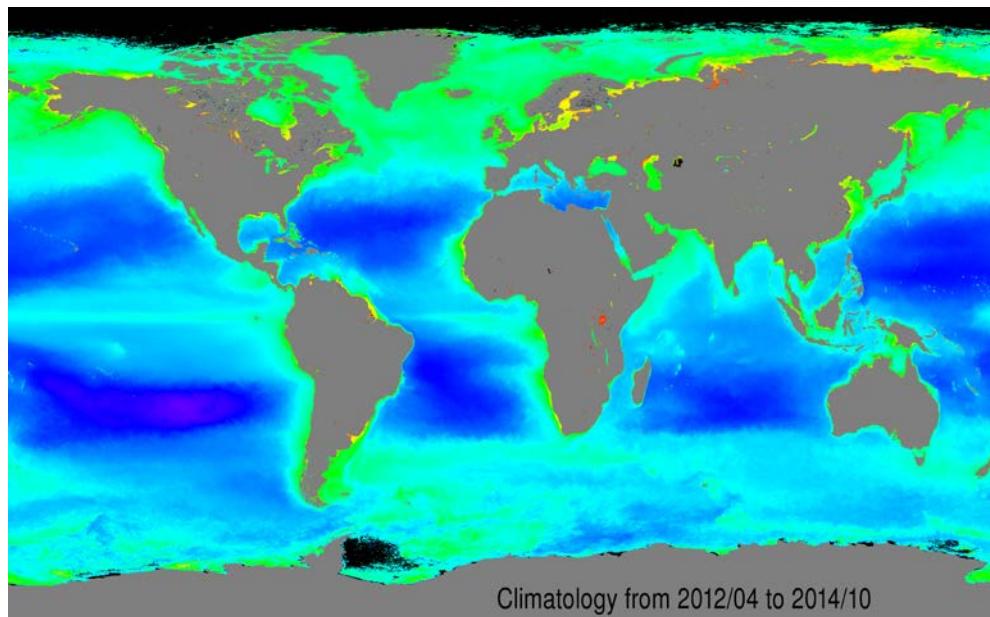
$I_0$  – ground radiation;  $K_d(490)$  – diffuse attenuation coefficient in water

Phytoplankton Functional Types (PFTs) (Arnold et al., 2009)

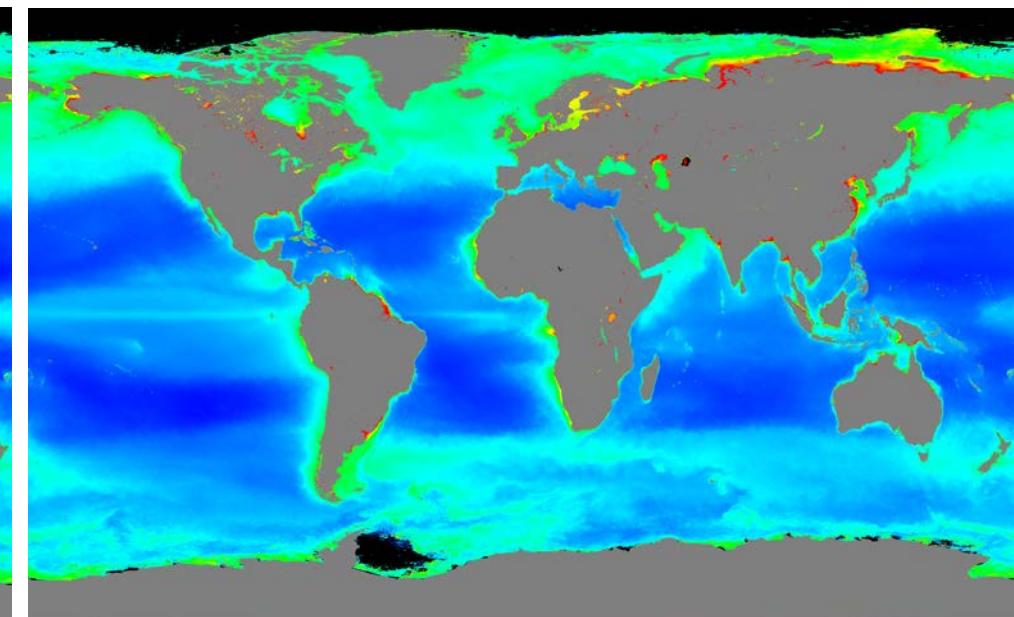
Determine emission factor (EF) and abundance (f);  
No data available from JPSS yet, using SeaWiFS climatological data

# Chlorophyll-a and $K_d(490)$

- ❖ **Sensor/Satellite:** Visible Infrared Imaging Radiometer Suite (VIIRS) on SNPP
- ❖ **Ocean Color Data Processing:**
  - Multi-Sensor Level-1 to Level-2 (MSL12) is used for VIIRS ocean color data processing
  - Routine ocean color data production from SDR (Level-1B) to ocean color EDR (Level-2), and to global Level-3 data, including  $nL_w$ , chlorophyll-a, and  $K_d(490)$ .
  - Level 3: Products are mapped to the CoastWatch geographic regions
- ❖ **Algorithms (Ocean Color EDR Team):**
  - Chlorophyll-a concentration: VIIRS OC3 algorithm
  - Diffuse attenuation coefficient at 490 nm  $K_d(490)$ : *Wang et al. (2009)* algorithm



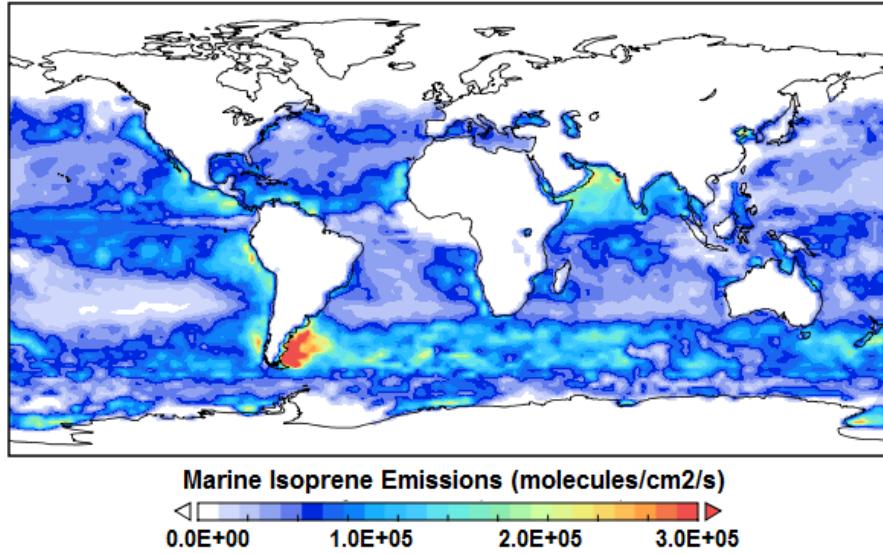
**Chlorophyll-a**



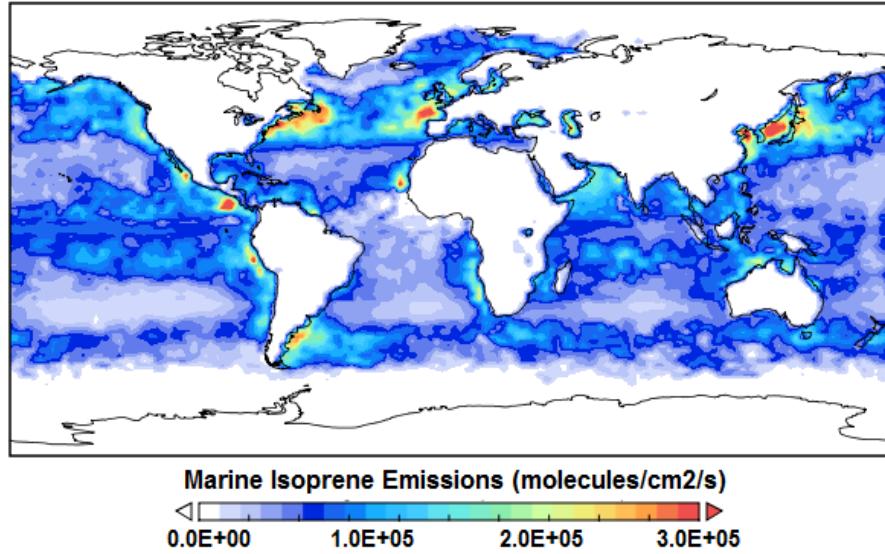
**$K_d(490)$**

# Global Distribution of Marine Isoprene

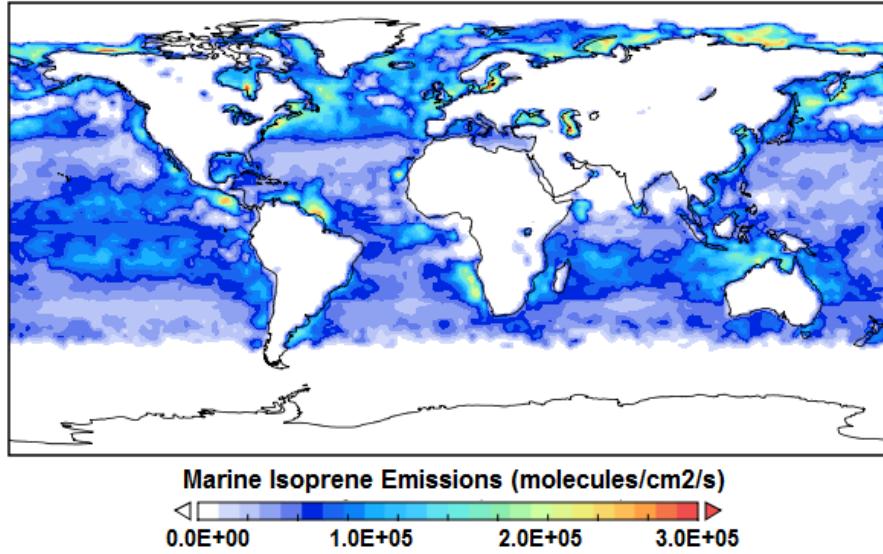
JAN



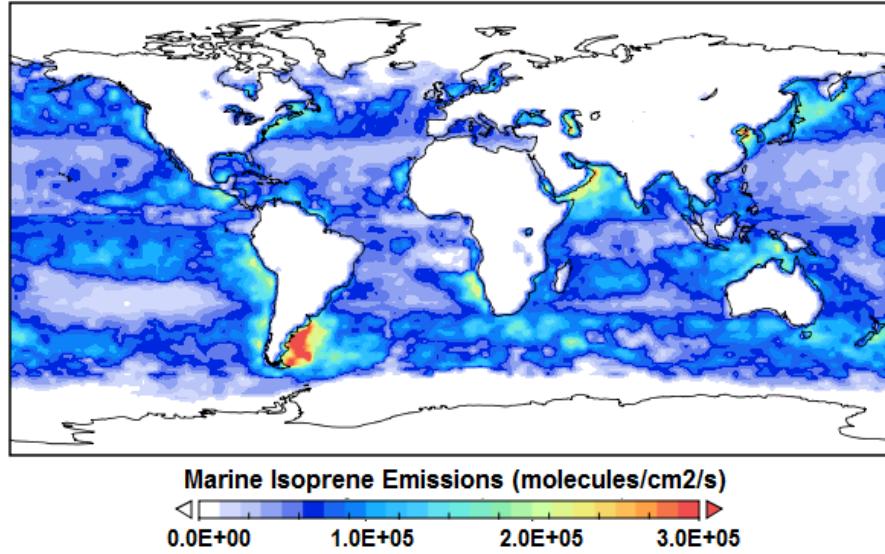
APR



JUL



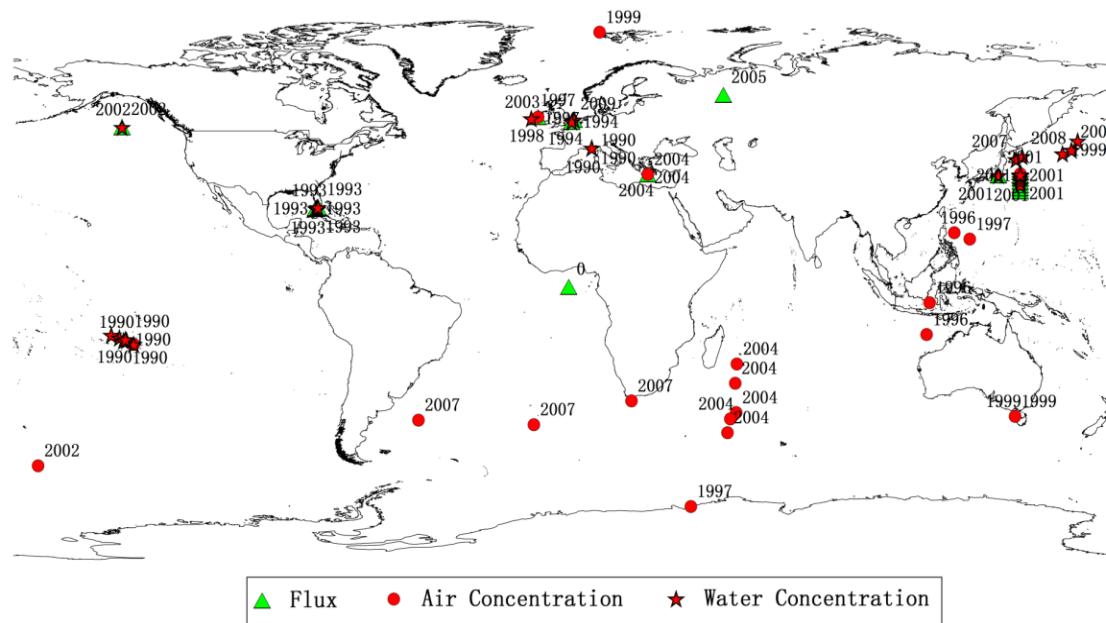
OCT



# Isoprene Observations and Validation

**Issue:** Some data can not be directly used for product validation.

**Reprocessing Approach:** Air-sea mass transfer.



**Convert seawater conc into flux:**

$$E_{iso} = K_{AS} * (C_W - H * C_A)$$

$K_{AS}$  – exchange coeff.;

$C_W$  – isop. conc. in water

$C_A$  – isop. conc. in the air

$H$  – Henry's law constant;

**Calculate exchange coefficient based on wind speed:**

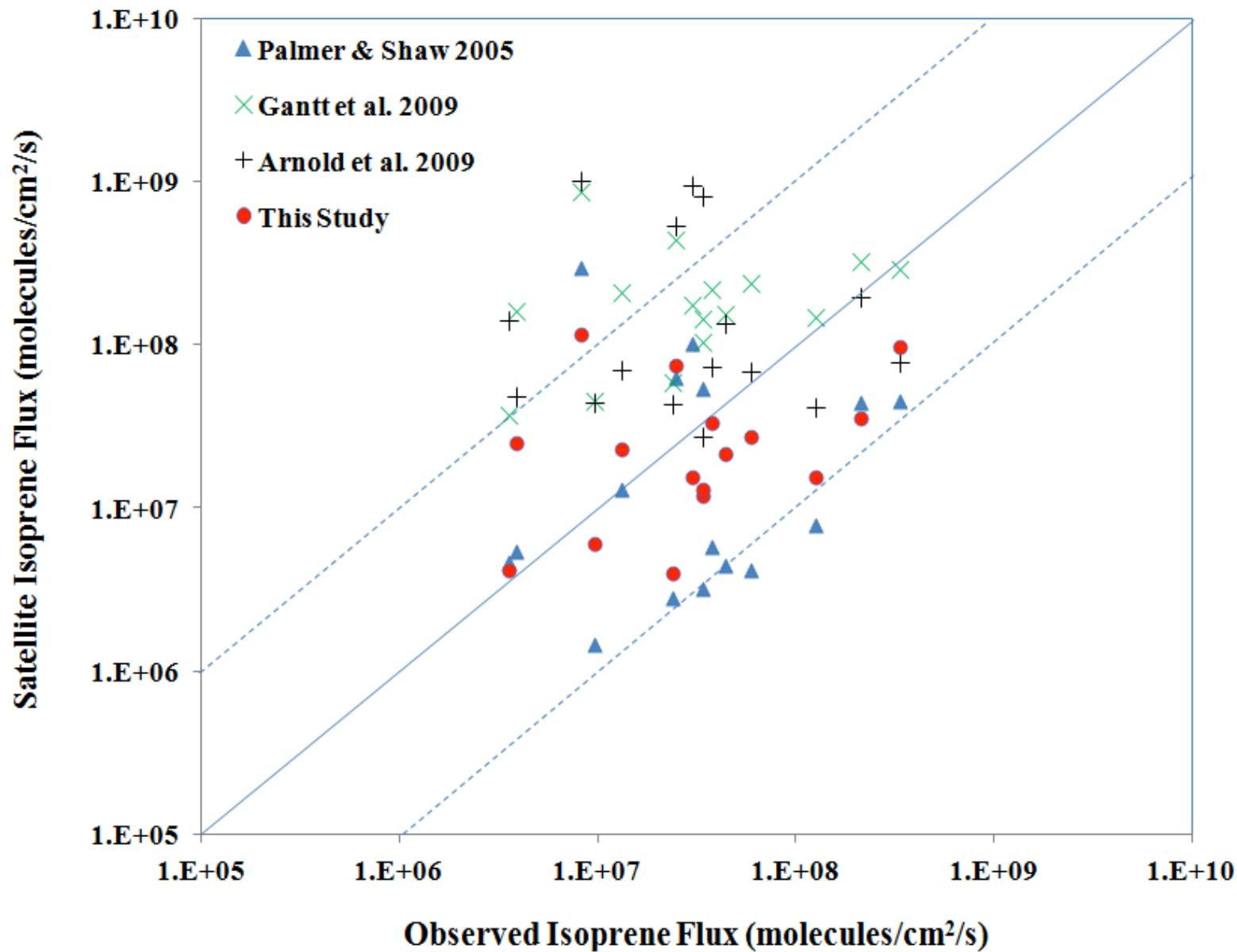
$$K_{AS} = 0.31 * U^2 ((3913.15 - 162.13T + 2.67T^2 - 0.012T^3) / 660)^{-0.5}$$

$U$  – surface wind speed;  $T$  – Sea surface Temperature

(Wanninkhof et al., 2004)



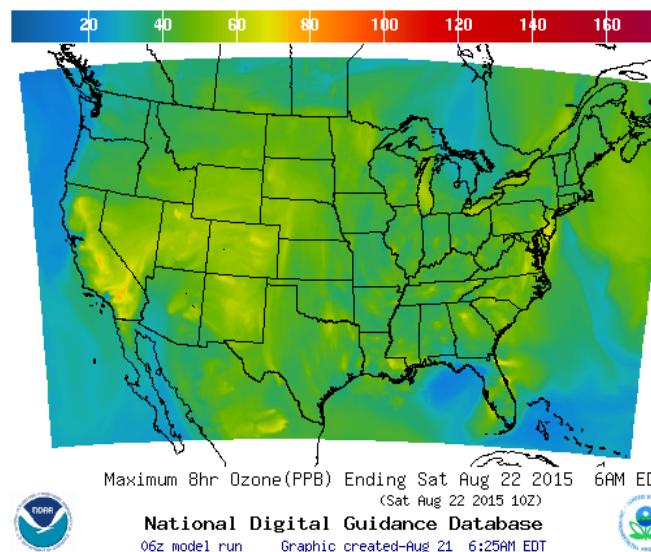
# Isoprene Product Validation (Cont.)



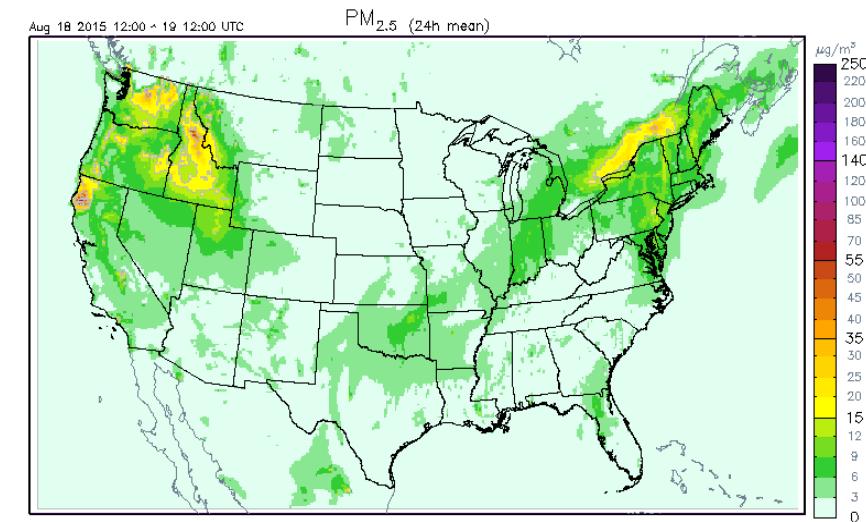
# NOAA National Air Quality Forecast Capability (NAQFC)

- ❖ Developed by OAR/Air Resources Laboratory; Operated by National Weather Service (NWS) (PM: I. Stajner).
- ❖ Provides national numeric air quality guidance for ozone (operational product) and PM<sub>2.5</sub> (particulate matter with diameter < 2.5 μm);

O<sub>3</sub> Forecasting



PM<sub>2.5</sub> Forecasting



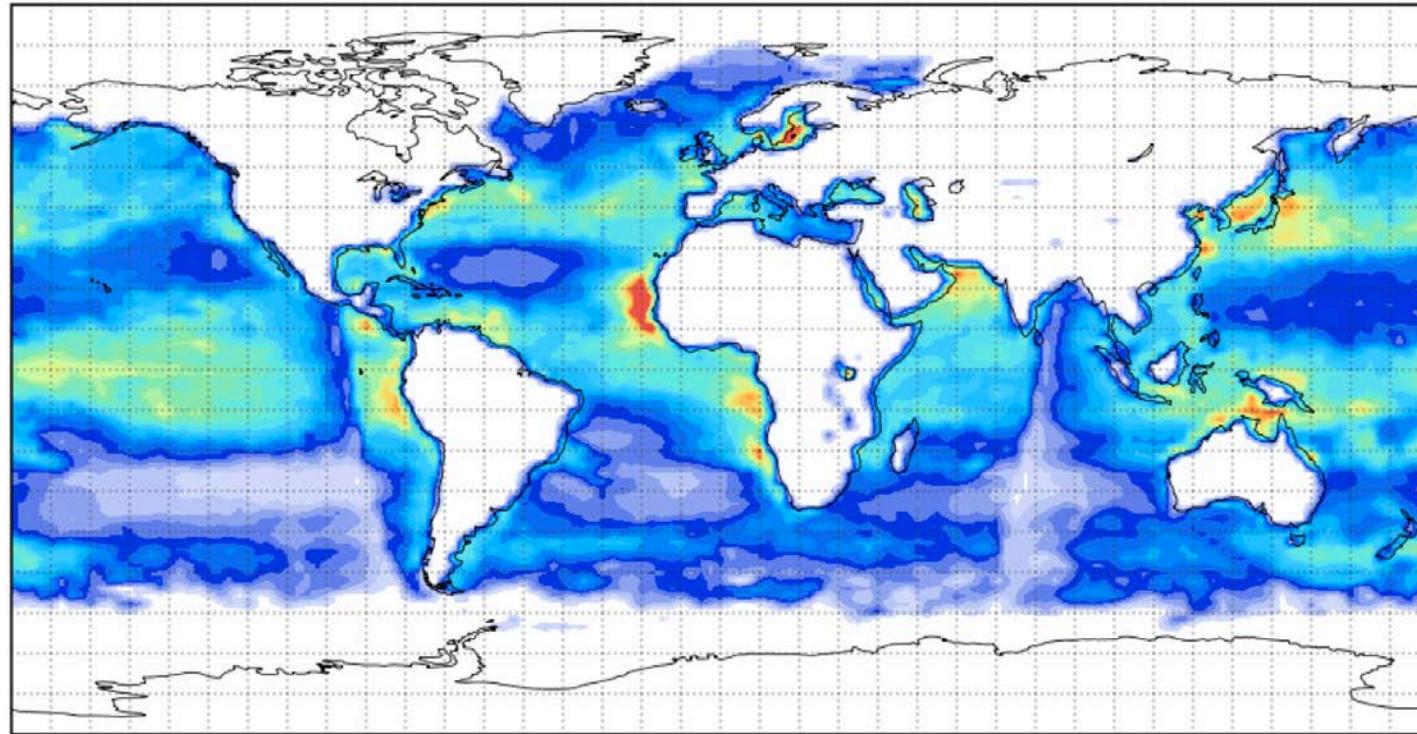
<http://airquality.weather.gov/>

**NAQFC is one of the major gateways to disseminate NOAA satellite observations and model prediction of air quality to the public.**

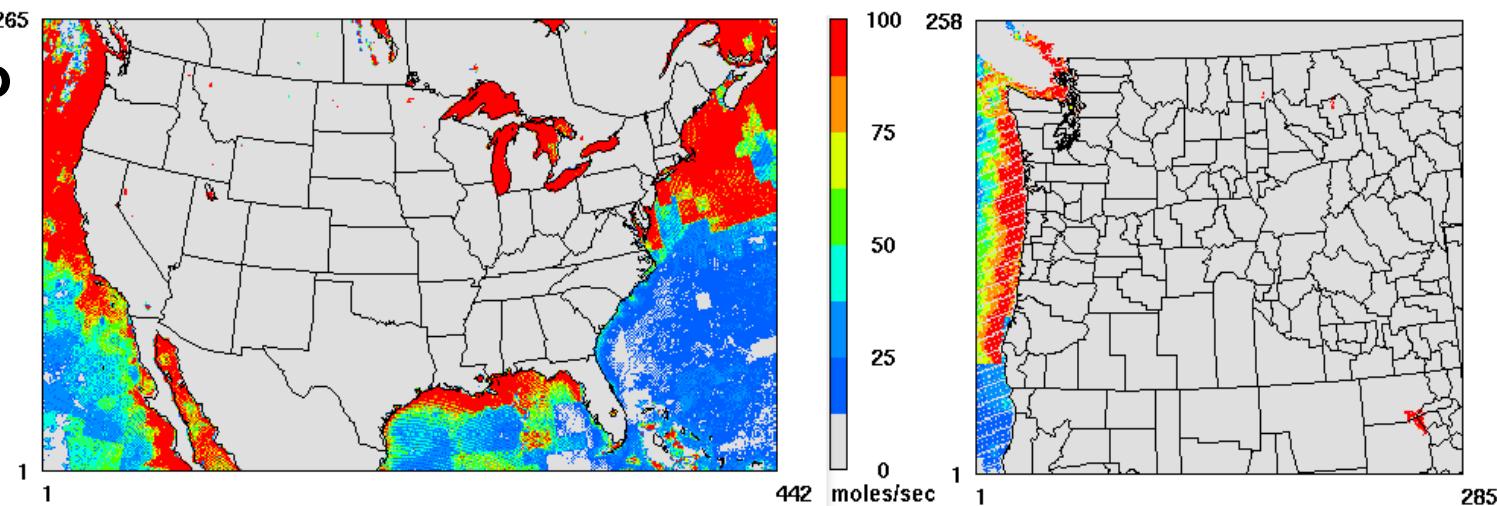
# Isoprene Applications: National and regional air quality forecasting



Global  
Isoprene  
(April 2014)



Isoprene into  
model  
domains



# Conclusions

- Satellite-measured ocean color products can provide global ocean water optical, biological, and biogeochemical properties.
- VIIRS is now providing high quality ocean color products in the global open oceans. VIIRS ocean color data can be used for various applications, e.g., producing global Marine Isoprene Emission product.
- Some validation results from satellite-measured marine isoprene emission results show quite promising.
- VIIRS-derived global Marine Isoprene Emission product shows quite promising and provide an effective tool to monitor marine isoprene emissions in the global ocean, as well as for improving global and regional air quality forecasting model.

*Thank You!*